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(54) **USE OF CAPACITANCE TO ANALYZE  
POLYCRYSTALLINE DIAMOND**

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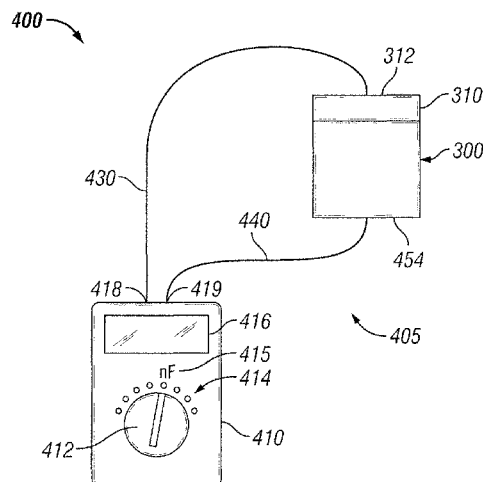
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(57) **ABSTRACT**

A method, system, and apparatus for non-destructively char-  
acterizing one or more regions within an ultra-hard polycrys-  
talline structure using capacitance measurements. The appa-  
ratus includes a capacitance measuring device having a  
positive and negative terminal, a leached component com-  
prising a polycrystalline structure, a first wire, and a second  
wire. The leached component includes a first surface and an  
opposing second surface. The first wire electrically couples  
the positive terminal to one of the surfaces of the leached  
component and the second wire electrically couples the nega-  
tive terminal to the other surface of the leached component.  
The capacitance is measured one or more times and compared  
to a calibration curve to determine an estimated leaching  
depth within the polycrystalline structure. A data scattering  
range is ascertained to determine a relative porosity of the  
polycrystalline structure or the leaching quality within the  
polycrystalline structure.

**18 Claims, 7 Drawing Sheets**



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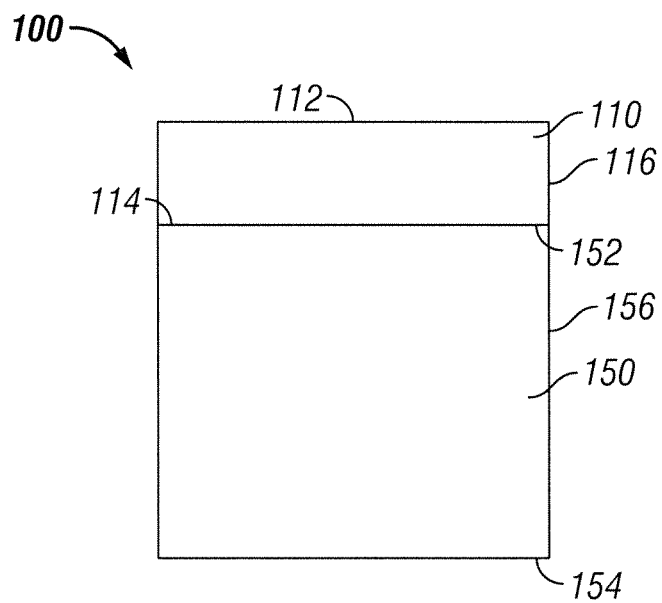
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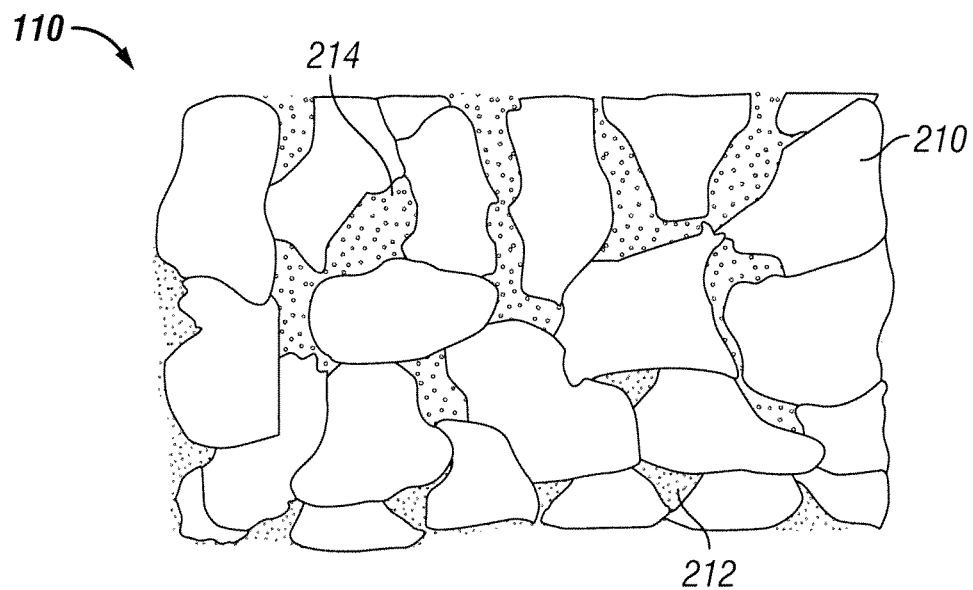
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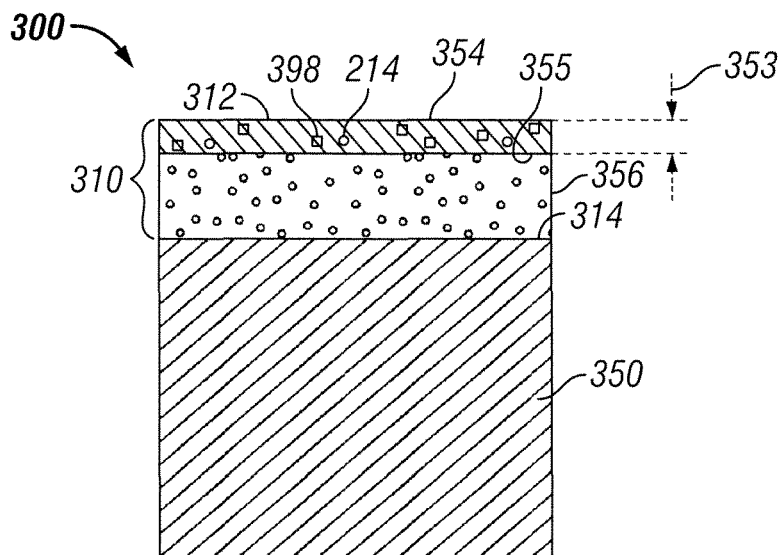
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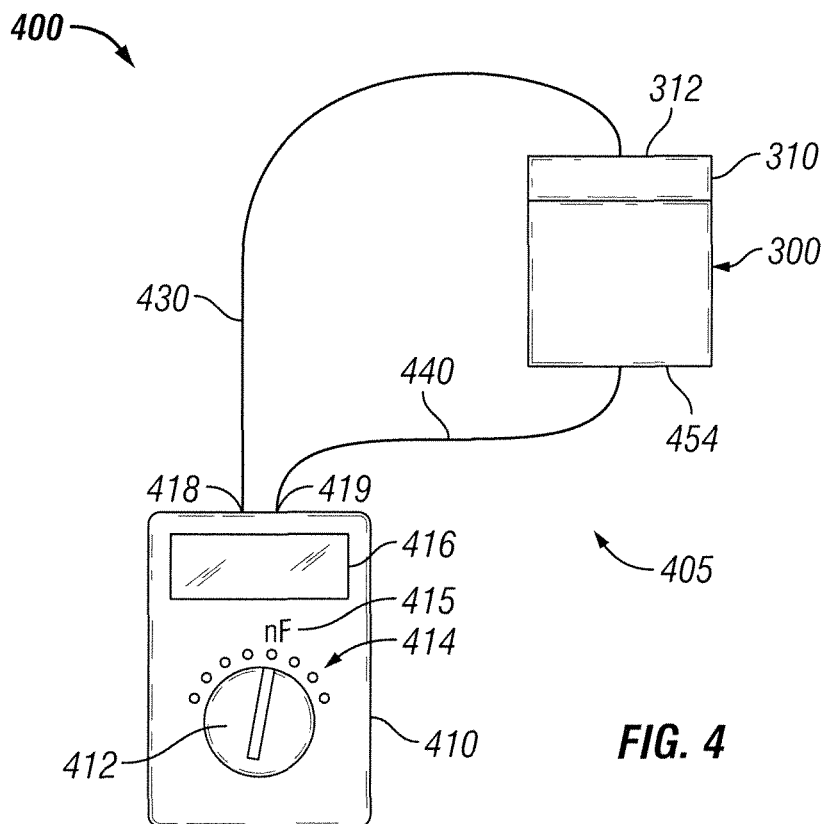
**FIG. 1**  
(Prior Art)



**FIG. 2**  
(Prior Art)



**FIG. 3**  
(Prior Art)



**FIG. 4**

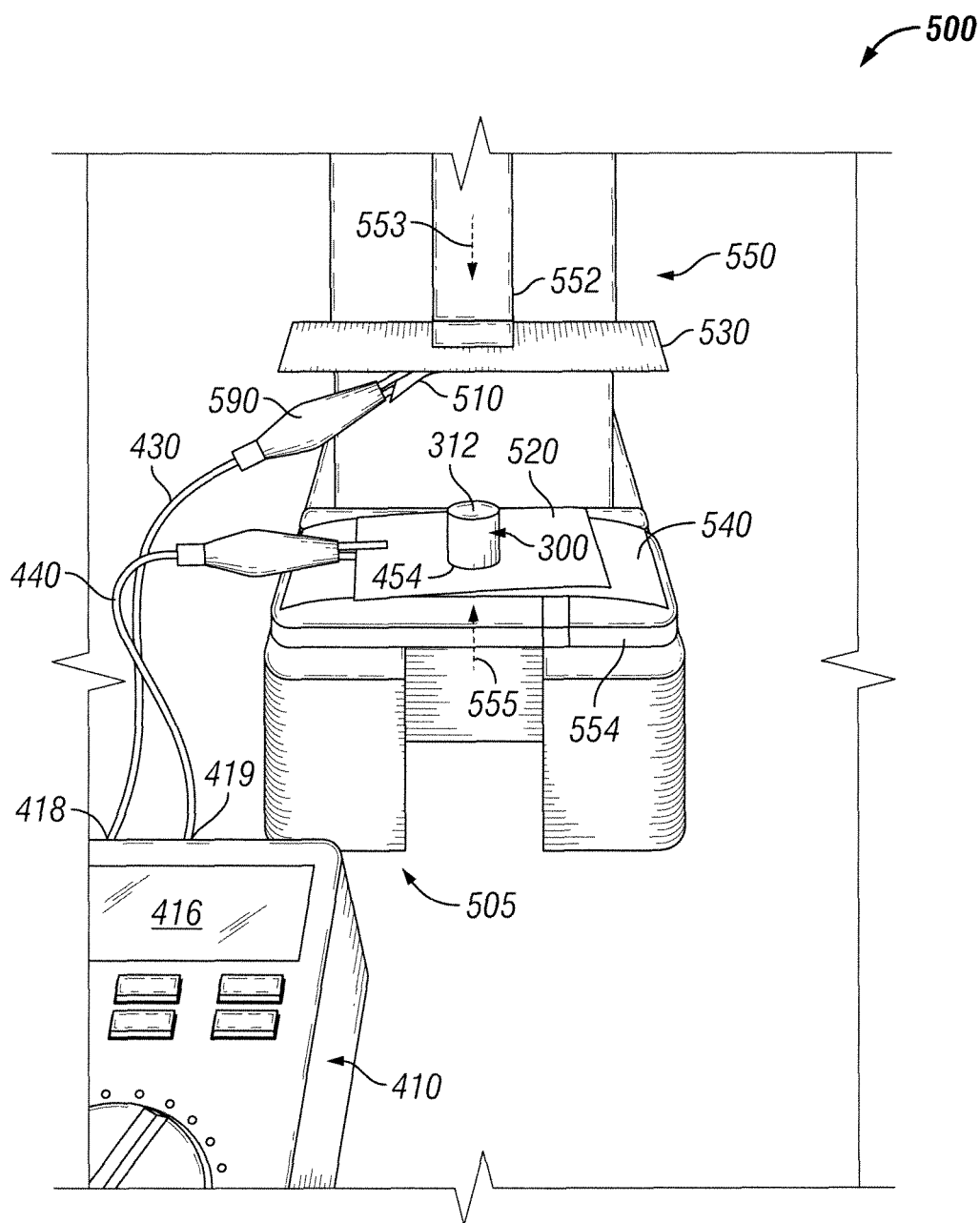
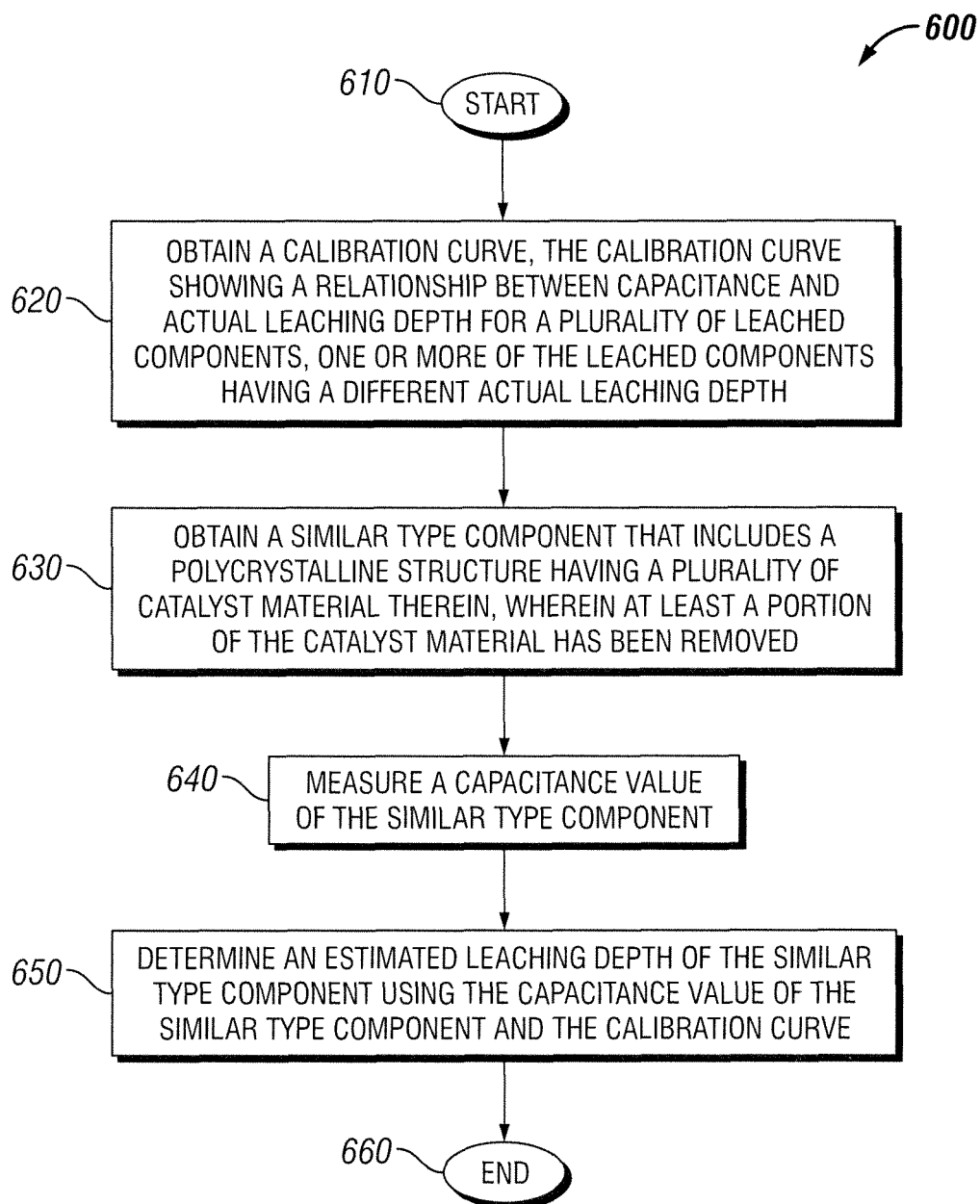


FIG. 5

**FIG. 6**

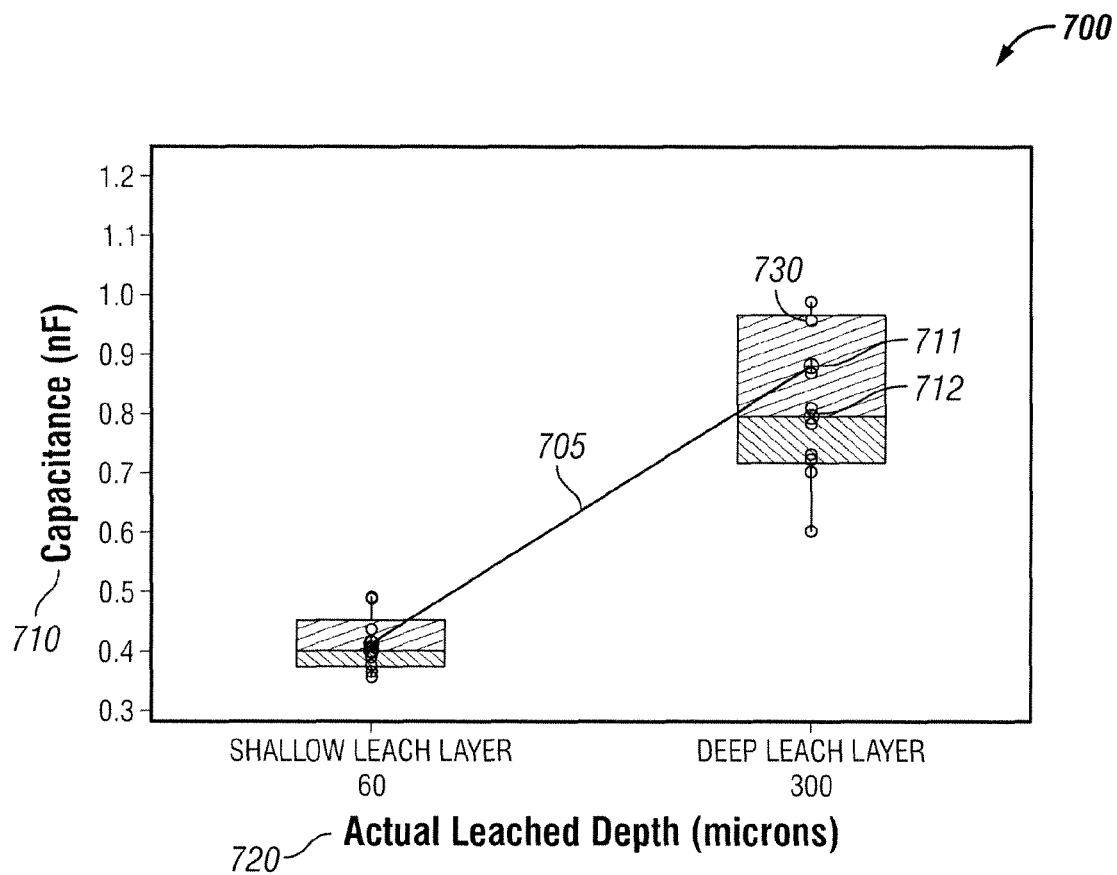
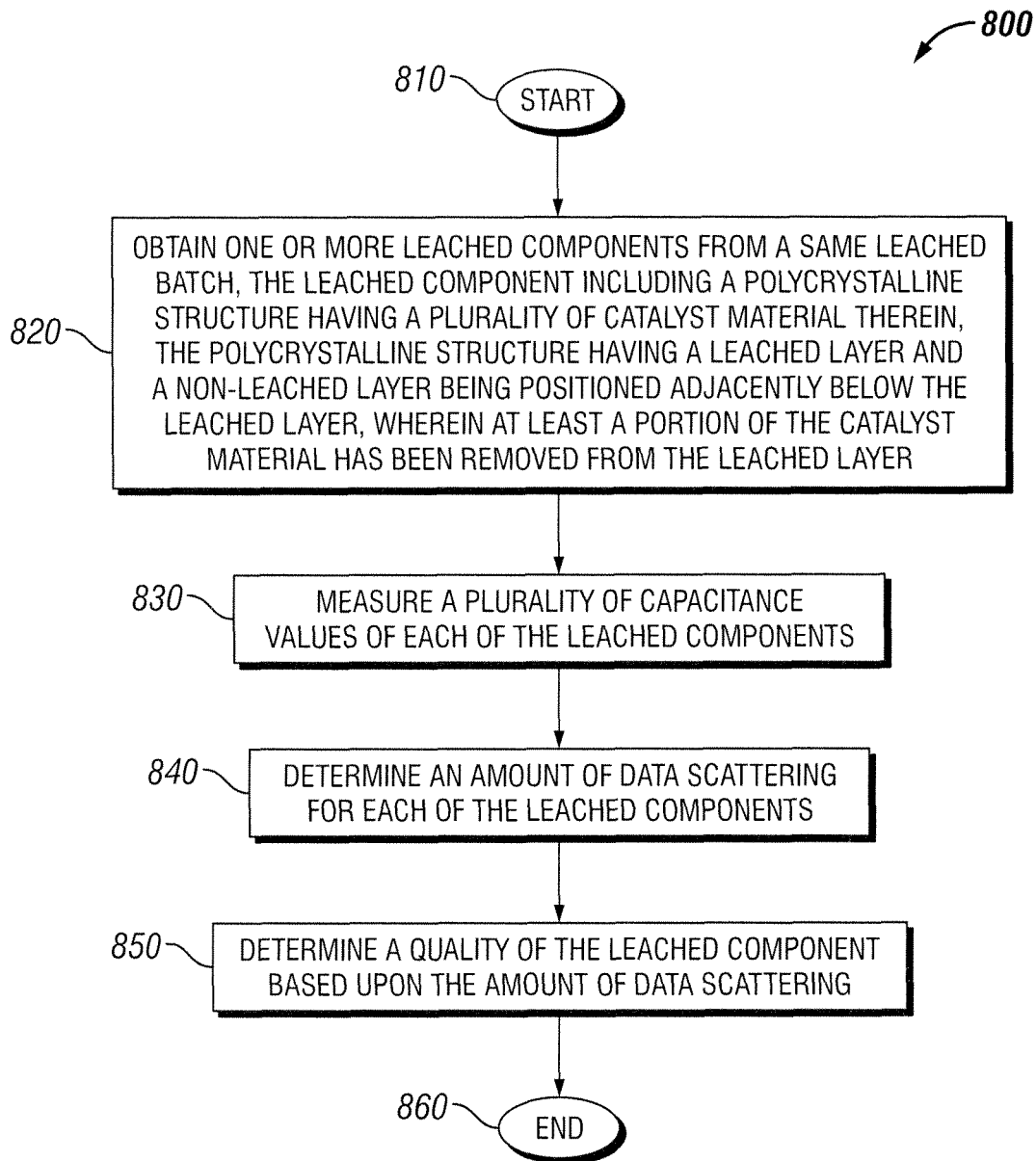


FIG. 7

**FIG. 8**



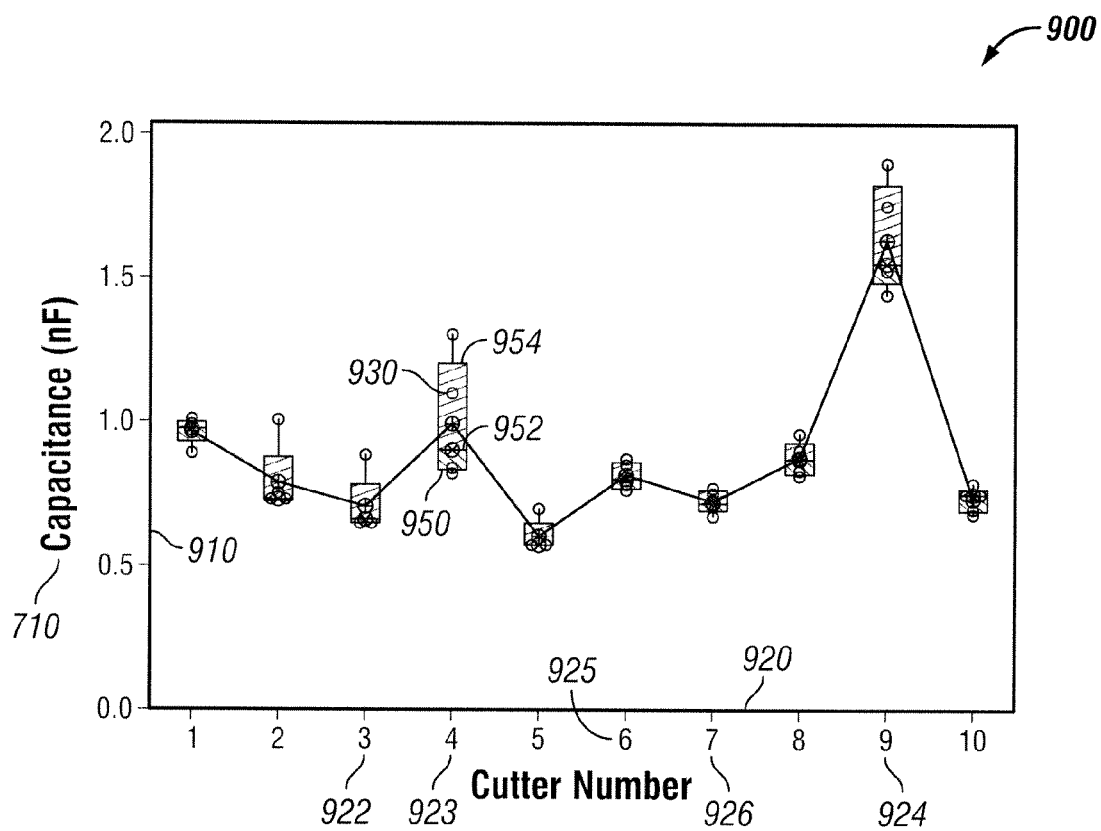


FIG. 9

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# USE OF CAPACITANCE TO ANALYZE POLYCRYSTALLINE DIAMOND

## RELATED APPLICATIONS

The present application is related to U.S. patent application Ser. No. 13/401,231, entitled "Use of Eddy Currents to Analyze Polycrystalline Diamond" and filed on Feb. 21, 2012, U.S. patent application Ser. No. 13/401,335, entitled "Use of Capacitance and Eddy Currents to Analyze Polycrystalline Diamond" and filed on Feb. 21, 2012, and U.S. patent application Ser. No. 13/401,452, entitled "Method To Improve The Performance Of A Leached Cutter" and filed on Feb. 21, 2012, which are all incorporated by reference herein.

## TECHNICAL FIELD

The present invention relates generally to a method and apparatus for measuring characteristics of one or more regions within an ultra-hard polycrystalline structure; and more particularly, to a non-destructive method and apparatus for measuring the leaching depth within the ultra-hard polycrystalline structure and/or characterizing at least a portion of the ultra-hard polycrystalline structure, such as the ones used in forming polycrystalline diamond compact ("PDC") cutters, using at least capacitance measurements.

## BACKGROUND

Polycrystalline diamond compacts ("PDC") have been used in industrial applications, including rock drilling applications and metal machining applications. Such compacts have demonstrated advantages over some other types of cutting elements, such as better wear resistance and impact resistance. The PDC can be formed by sintering individual diamond particles together under the high pressure and high temperature ("HPHT") conditions referred to as the "diamond stable region," which is typically above forty kilobars and between 1,200 degrees Celsius and 2,000 degrees Celsius, in the presence of a catalyst/solvent which promotes diamond-diamond bonding. Some examples of catalyst/solvents for sintered diamond compacts are cobalt, nickel, iron, and other Group VIII metals. PDCs usually have a diamond content greater than seventy percent by volume, with about eighty percent to about ninety-eight percent being typical. An unbacked PDC can be mechanically bonded to a tool (not shown), according to one example. Alternatively, the PDC is bonded to a substrate, thereby forming a PDC cutter, which is typically insertable within a downhole tool (not shown), such as a drill bit or a reamer.

FIG. 1 shows a side view of a PDC cutter 100 having a polycrystalline diamond ("PCD") cutting table 110, or compact, in accordance with the prior art. Although a PCD cutting table 110 is described in the exemplary embodiment, other types of cutting tables, including polycrystalline boron nitride ("PCBN") compacts, are used in alternative types of cutters. Referring to FIG. 1, the PDC cutter 100 typically includes the PCD cutting table 110 and a substrate 150 that is coupled to the PCD cutting table 110. The PCD cutting table 110 is about one hundred thousandths of an inch (2.5 millimeters) thick; however, the thickness is variable depending upon the application in which the PCD cutting table 110 is to be used.

The substrate 150 includes a top surface 152, a bottom surface 154, and a substrate outer wall 156 that extends from the circumference of the top surface 152 to the circumference of the bottom surface 154. The PCD cutting table 110

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includes a cutting surface 112, an opposing surface 114, and a PCD cutting table outer wall 116 that extends from the circumference of the cutting surface 112 to the circumference of the opposing surface 114. The opposing surface 114 of the PCD cutting table 110 is coupled to the top surface 152 of the substrate 150. Typically, the PCD cutting table 110 is coupled to the substrate 150 using a high pressure and high temperature ("HPHT") press. However, other methods known to people having ordinary skill in the art can be used to couple the PCD cutting table 110 to the substrate 150. In one embodiment, upon coupling the PCD cutting table 110 to the substrate 150, the cutting surface 112 of the PCD cutting table 110 is substantially parallel to the substrate's bottom surface 154. Additionally, the PDC cutter 100 has been illustrated as having a right circular cylindrical shape; however, the PDC cutter 100 is shaped into other geometric or non-geometric shapes in other exemplary embodiments. In certain exemplary embodiments, the opposing surface 114 and the top surface 152 are substantially planar; however, the opposing surface 114 and the top surface 152 are non-planar in other exemplary embodiments. Additionally, according to some exemplary embodiments, a bevel (not shown) is formed around at least the circumference of the cutting surface 112.

According to one example, the PDC cutter 100 is formed by independently forming the PCD cutting table 110 and the substrate 150, and thereafter bonding the PCD cutting table 110 to the substrate 150. Alternatively, the substrate 150 is initially formed and the PCD cutting table 110 is subsequently formed on the top surface 152 of the substrate 150 by placing polycrystalline diamond powder onto the top surface 152 and subjecting the polycrystalline diamond powder and the substrate 150 to a high temperature and high pressure process. Alternatively, the substrate 150 and the PCD cutting table 110 are formed and bonded together at about the same time. Although a few methods of forming the PDC cutter 100 have been briefly mentioned, other methods known to people having ordinary skill in the art can be used.

According to one example for forming the PDC cutter 100, the PCD cutting table 110 is formed and bonded to the substrate 150 by subjecting a layer of diamond powder and a mixture of tungsten carbide and cobalt powders to HPHT conditions. The cobalt is typically mixed with tungsten carbide and positioned where the substrate 150 is to be formed. The diamond powder is placed on top of the cobalt and tungsten carbide mixture and positioned where the PCD cutting table 110 is to be formed. The entire powder mixture is then subjected to HPHT conditions so that the cobalt melts and facilitates the cementing, or binding, of the tungsten carbide to form the substrate 150. The melted cobalt also diffuses, or infiltrates, into the diamond powder and acts as a catalyst for synthesizing diamond bonds and forming the PCD cutting table 110. Thus, the cobalt acts as both a binder for cementing the tungsten carbide and as a catalyst/solvent for sintering the diamond powder to form diamond-diamond bonds. The cobalt also facilitates in forming strong bonds between the PCD cutting table 110 and the cemented tungsten carbide substrate 150.

Cobalt has been a preferred constituent of the PDC manufacturing process. Traditional PDC manufacturing processes use cobalt as the binder material for forming the substrate 150 and also as the catalyst material for diamond synthesis because of the large body of knowledge related to using cobalt in these processes. The synergy between the large bodies of knowledge and the needs of the process have led to using cobalt as both the binder material and the catalyst material. However, as is known in the art, alternative metals, such as iron, nickel, chromium, manganese, and tantalum,

and other suitable materials, can be used as a catalyst for diamond synthesis. When using these alternative materials as a catalyst for diamond synthesis to form the PCD cutting table 110, cobalt, or some other material such as nickel chrome or iron, is typically used as the binder material for cementing the tungsten carbide to form the substrate 150. Although some materials, such as tungsten carbide and cobalt, have been provided as examples, other materials known to people having ordinary skill in the art can be used to form the substrate 150, the PCD cutting table 110, and the bonds between the substrate 150 and the PCD cutting table 110.

FIG. 2 is a schematic microstructural view of the PCD cutting table 110 of FIG. 1 in accordance with the prior art. Referring to FIGS. 1 and 2, the PCD cutting table 110 has diamond particles 210 bonded to other diamond particles 210, one or more interstitial spaces 212 formed between the diamond particles 210, and cobalt 214, or some other catalyst, deposited within one or more of the interstitial spaces 212. During the sintering process, the interstitial spaces 212, or voids, are formed between the carbon-carbon bonds and are located between the diamond particles 210. The diffusion of cobalt 214 into the diamond powder results in cobalt 214 being deposited within these interstitial spaces 212 that are formed within the PCD cutting table 110 during the sintering process.

Once the PCD cutting table 110 is formed and placed into operation, the PCD cutting table 110 is known to wear quickly when the temperature reaches a critical temperature. This critical temperature is about 750 degrees Celsius and is reached when the PCD cutting table 110 is cutting rock formations or other known materials. The high rate of wear is believed to be caused by the differences in the thermal expansion rate between the diamond particles 210 and the cobalt 214 and also by the chemical reaction, or graphitization, that occurs between cobalt 214 and the diamond particles 210. The coefficient of thermal expansion for the diamond particles 210 is about  $1.0 \times 10^{-6}$  millimeters<sup>-1</sup> × Kelvin<sup>-1</sup> ("mm<sup>-1</sup> K<sup>-1</sup>"), while the coefficient of thermal expansion for the cobalt 214 is about  $13.0 \times 10^{-6}$  mm<sup>-1</sup> K<sup>-1</sup>. Thus, the cobalt 214 expands much faster than the diamond particles 210 at temperatures above this critical temperature, thereby making the bonds between the diamond particles 210 unstable. The PCD cutting table 110 becomes thermally degraded at temperatures above about 750 degrees Celsius and its cutting efficiency deteriorates significantly.

Efforts have been made to slow the wear of the PCD cutting table 110 at these high temperatures. These efforts include performing a leaching process on the PCD cutting table 110, which removes some of the cobalt 214 from the interstitial spaces 212. These leaching processes, which includes, but is not limited to, an acid leaching process and/or an electrolytic leaching process, is known to persons having ordinary skill in the art and is not described herein for the sake of brevity. By removing some of the cobalt 214, or catalyst, from the PCD cutting table 110, the thermal degradation of the PCD structure is reduced.

FIG. 3 shows a cross-section view of a leached PDC cutter 300 having a PCD cutting table 310 that has been at least partially leached in accordance with the prior art. Referring to FIG. 3, the PDC cutter 300 includes the PCD cutting table 310 coupled to a substrate 350. The substrate 350 is similar to substrate 150 (FIG. 1) and is not described again for the sake of brevity. The PCD cutting table 310 is similar to the PCD cutting table 110 (FIG. 1), but includes a leached layer 354 and an unleached layer 356. The leached layer 354 extends from the cutting surface 312, which is similar to the cutting surface 112 (FIG. 1), towards an opposing surface 314, which

is similar to the opposing surface 114 (FIG. 1). In the leached layer 354, at least a portion of the cobalt 214 has been removed from within the interstitial spaces 212 (FIG. 2) using at least one leaching process mentioned above. Thus, the leached layer 354 has been leached to a desired depth 353. However, during the leaching process, one or more by-product materials 398 are formed and deposited within some of the interstitial spaces 212 (FIG. 2) in the leached layer 354. The unleached layer 356 is similar to the PCD cutting table 150 (FIG. 1) and extends from the end of the leached layer 354 to the opposing surface 314. In the unleached layer 356, the cobalt 214 (FIG. 2) remains within the interstitial spaces 212 (FIG. 2). Although a boundary line 355 is formed between the leached layer 354 and the unleached layer 356 and is depicted as being substantially linear, the boundary line 355 can be non-linear.

The leached PDC cutters 300 are leached to different desired depths 353 and how deep the cutter 300 has been leached has an effect on the performance of the cutter 300. Conventionally, the leached depth 353 of the cutter 300 is measured, or determined, by cutting the cutter 300 vertically in half and then subsequently polishing the cutter 300. The leached depth 353 is visually measured under a microscope or similar magnifying device. This process is rather tedious and cumbersome as it involves cutting the cutter 300, such as by electrical discharge machining ("EDM"), mounting, grinding, and polishing the cutter 300, and performing an analysis under a microscope. Additionally, this process destroys the cutter 300 from subsequently being used. The leached depth 353 that is determined in this manner is assumed to be the same leached depth in other cutters that were leached in the same batch.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features and aspects of the invention are best understood with reference to the following description of certain exemplary embodiments, when read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a side view of a PDC cutter having a polycrystalline diamond cutting table, or compact, in accordance with the prior art;

FIG. 2 is a schematic microstructural view of the PCD cutting table of FIG. 1 in accordance with the prior art;

FIG. 3 is a cross-section view of a PDC cutter having a PCD cutting table that has been at least partially leached in accordance with the prior art;

FIG. 4 is a schematic view of a capacitance measuring system in accordance to one exemplary embodiment of the present invention;

FIG. 5 is a schematic view of a capacitance measuring system in accordance to another exemplary embodiment of the present invention;

FIG. 6 is a flowchart depicting a non-destructive leaching depth estimation method in accordance with an exemplary embodiment of the present invention;

FIG. 7 is a graphical chart depicting a calibration curve that shows a relationship between capacitance and actual leaching depth for a plurality of leached components in accordance with an exemplary embodiment of the present invention;

FIG. 8 is a flowchart depicting a microstructural quality determination method in accordance with an exemplary embodiment of the present invention; and

FIG. 9 is a data scattering chart that shows the measured capacitance for a plurality of cutters in accordance with an exemplary embodiment of the present invention.

The drawings illustrate only exemplary embodiments of the invention and are therefore not to be considered limiting of its scope, as the invention may admit to other equally effective embodiments.

#### BRIEF DESCRIPTION OF EXEMPLARY EMBODIMENTS

The present invention is directed to a non-destructive method and apparatus for measuring the leaching depth within an ultra-hard polycrystalline structure and/or characterizing at least a portion of the ultra-hard polycrystalline structure, such as the ones used in forming polycrystalline diamond compact ("PDC") cutters, using at least capacitance measurements. Although the description of exemplary embodiments is provided below in conjunction with a PDC cutter, alternate embodiments of the invention may be applicable to other types of polycrystalline structures including, but not limited to, PCBN cutters. Further, according to some exemplary embodiments, one or more portions of the methods described below is implemented using an electronic measuring device. For example, the capacitance is measured using a capacitance measuring device. The invention is better understood by reading the following description of non-limiting, exemplary embodiments with reference to the attached drawings, wherein like parts of each of the figures are identified by like reference characters, and which are briefly described as follows.

FIG. 4 is a schematic view of a capacitance measuring system 400 in accordance to one exemplary embodiment of the present invention. Referring to FIG. 4, the capacitance measuring system 400 includes a capacitance measuring device 410, the leached PDC cutter 300, a first wire 430, and a second wire 440. Although certain components have been enumerated as being included in the capacitance measuring system 400, additional components are included in other exemplary embodiments. Additionally, although the description provided below has been provided with respect to the leached PDC cutter 300, a different component, such as the PCD cutting table 310 alone or other component that includes another type of leached polycrystalline structure, is used in lieu of the leached PDC cutter 300. Additionally, although the description provided below has been provided with respect to the leached PDC cutter 300, a different component, such as a chemically cleaned leached PDC cutter (not shown), is used in lieu of the leached PDC cutter 300. The chemically cleaned leached PDC cutter has had at least a portion of the by-product materials 398 (FIG. 3) removed by using one or more processes described in related application entitled, "Method To Improve The Performance Of A Leached Cutter", which has been mentioned above and incorporated by reference herein. The leached PDC cutter 300 has been previously described with respect to FIG. 3 and is not repeated again herein for the sake of brevity.

The capacitance measuring device 410 is a device that measures the capacitance of an energy storage device, which is the leached PDC cutter 300 in the instant exemplary embodiment. Capacitance is a measure of the amount of electric potential energy stored, or separated, for a given electric potential. A common form of energy storage device is a parallel-plate capacitor. In the instant exemplary embodiment, the leached PDC cutter 300 is an example of the parallel-plate capacitor. The capacitance of the energy storage device is typically measured in farads, or nanofarads.

One example of the capacitance measuring device 410 is a multi-meter; however, other capacitance measuring devices known to people having ordinary skill in the art are used in

one or more alternative exemplary embodiments. The multi-meter 410 includes a positionable dial 412, a plurality of measurement settings 414, a display 416, a positive terminal 418, and a negative terminal 419. According to some exemplary embodiments, the positionable dial 412 is rotatable in a clockwise and/or counter-clockwise manner and is set to one of several available measurement settings 414. In the instant exemplary embodiment, the positionable dial 412 is set to a nanofaraday setting 415 so that the multi-meter 410 measures capacitance values. The display 416 is fabricated using polycarbonate, glass, plastic, or other known suitable material and communicates a measurement value, such as a capacitance value, to a user (not shown) of the multi-meter 410. The positive terminal 418 is electrically coupled to one end of the first wire 430, while the negative terminal 419 is electrically coupled to one end of the second wire 440.

The first wire 430 is fabricated using a copper wire or some other suitable conducting material or alloy known to people having ordinary skill in the art. According to some exemplary embodiments, the first wire 430 also includes a non-conducting sheath (not shown) that surrounds the copper wire and extends from about one end of the copper wire to an opposing end of the copper wire. The two ends of the copper wire are exposed and are not surrounded by the non-conducting sheath. In some exemplary embodiments, an insulating material (not shown) also surrounds the copper wire and is disposed between the copper wire and the non-conducting sheath. The insulating material extends from about one end of the non-conducting sheath to about an opposing end of the non-conducting sheath. As previously mentioned, one end of the first wire 430 is electrically coupled to the positive terminal 418, while the opposing end of the first wire 430 is electrically coupled to the cutting surface 312 of the leached PDC cutter 300. The opposing end of the first wire 430 is electrically coupled to the cutting surface 312 in one of several methods. In one example, the first wire 430 is electrically coupled to the cutting surface 312 using one or more fastening devices (not shown), such as a clamp, or using an equipment (not shown) that supplies a force to retain the first wire 430 in electrical contact with the cutting surface 312. In another example, a clamp (not shown) is coupled to the opposing end of the first wire 430 and a conducting component (not shown), such as aluminum foil, is coupled to, or placed in contact with, the cutting surface 312. The clamp is electrically coupled to the conducting component, thereby electrically coupling the first wire 430 to the cutting surface 312. Additional methods for coupling the first wire 430 to the cutting surface 312 can be used in other exemplary embodiments.

The second wire 440 is fabricated using a copper wire or some other suitable conducting material or alloy known to people having ordinary skill in the art. According to some exemplary embodiments, the second wire 440 also includes a non-conducting sheath (not shown) that surrounds the copper wire and extends from about one end of the copper wire to an opposing end of the copper wire. The two ends of the copper wire are exposed and are not surrounded by the non-conducting sheath. In some exemplary embodiments, an insulating material (not shown) also surrounds the copper wire and is disposed between the copper wire and the non-conducting sheath. The insulating material extends from about one end of the non-conducting sheath to an opposing end of the non-conducting sheath. As previously mentioned, one end of the second wire 440 is electrically coupled to the negative terminal 419, while the opposing end of the second wire 440 is electrically coupled to a bottom surface 454, which is similar to the bottom surface 154 (FIG. 1), of the leached PDC cutter 300. The second wire 440 is electrically coupled to the bottom

surface **454** in a similar manner as the first wire **430** is electrically coupled to the cutting surface **312**.

Hence, a circuit **405** is completed using the multi-meter **410**, the first wire **430**, the leached PDC cutter **300**, and the second wire **440**. The current is able to flow from the positive terminal **418** of the multi-meter **410** to the cutting surface **312** of the leached PDC cutter **300** through the first wire **430**. The current then flows through the leached PDC cutter **300** to the bottom surface **454** of the leached PDC cutter **300**. When the multi-meter **410** is turned on, a voltage differential exists between the cutting surface **312** and the bottom surface **454**. The current then flows from the bottom surface **454** to the negative terminal **419** of the multi-meter **410** through the second wire **440**. The capacitance measurement of the leached PDC cutter **300** is determined when the value displayed on the display **416** reaches a peak value or remains constant for a period of time.

FIG. **5** is a schematic view of a capacitance measuring system **500** in accordance to another exemplary embodiment of the present invention. Referring to FIG. **5**, the capacitance measuring system **500** includes the capacitance measuring device **410**, the leached PDC cutter **300**, the first wire **430**, the second wire **440**, a first conducting material **510**, a second conducting material **520**, a first insulating material **530**, a second insulating material **540**, and an Arbor Press **550**. Although certain components have been enumerated as being included in the capacitance measuring system **500**, additional components are included in other exemplary embodiments. Further, although certain components have been enumerated as being included in the capacitance measuring system **500**, alternative components having similar functions as the enumerated components are used in alternative exemplary embodiments. Additionally, although the description provided below has been provided with respect to the leached PDC cutter **300**, a different component, such as the PCD cutting table **310** (FIG. **3**) alone or other component that includes another type of leached polycrystalline structure, is used in lieu of the leached PDC cutter **300**. Additionally, although the description provided below has been provided with respect to the leached PDC cutter **300**, a different component, such as the chemically cleaned leached PDC cutter mentioned above, is used in lieu of the leached PDC cutter **300**. The capacitance measuring device **410**, the leached PDC cutter **300**, the first wire **430**, and the second wire **440** have been previously described and are not repeated again herein for the sake of brevity.

The first conducting material **510** and the second conducting material **520** are similar to one another in certain exemplary embodiments, but are different in other exemplary embodiments. According to one exemplary embodiment, the conducting materials **510**, **520** are fabricated using aluminum foil; however, other suitable conducting materials can be used. The first conducting material **510** is positioned adjacently above and in contact with the cutting surface **312**. The second conducting material **520** is positioned adjacently below and in contact with the bottom surface **454**. The first conducting material **510** and the second conducting material **520** provide an area to which the first wire **430** and the second wire **440**, respectively, make electrical contact. Additionally, the first conducting material **510** and the second conducting material **520** assist in minimizing contact resistance with the cutting surface **312** and the bottom surface **454**, respectively, which is discussed in further detail below. In certain exemplary embodiments, the first conducting material **510** and the second conducting material **520** are the same shape and size; while in other exemplary embodiments, one of the conduct-

ing materials **510**, **520** is a different shape and/or size than the other conducting material **510**, **520**.

The first insulating material **530** and the second insulating material **540** are similar to one another in certain exemplary embodiments, but are different in other exemplary embodiments. According to one exemplary embodiment, the insulating materials **530**, **540** are fabricated using paper; however, other suitable insulating materials, such as rubber, can be used. The first insulating material **530** is positioned adjacently above and in contact with the first conducting material **510**. The second insulating material **540** is positioned adjacently below and in contact with the second conducting material **520**. The first insulating material **530** and the second insulating material **540** provide a barrier to direct current flow only through a circuit **505**, which is discussed in further detail below. In certain exemplary embodiments, the first insulating material **530** and the second insulating material **540** are the same shape and size; while in other exemplary embodiments, one of the insulating materials **530**, **540** is a different shape and/or size than the other insulating material **530**, **540**. Additionally, in certain exemplary embodiments, the insulating materials **530**, **540** is larger in size than its corresponding conducting material **510**, **520**. However, one or more of the insulating materials **530**, **540** is either larger or smaller than its corresponding conducting material **510**, **520** in alternative exemplary embodiments.

The Arbor Press **550** includes an upper plate **552** and a base plate **554**. The upper plate **552** is positioned above the base plate **554** and is movable towards the base plate **554**. In other exemplary embodiments, the base plate **554** is movable towards the upper plate **552**. The first insulating material **530**, the first conducting material **510**, the leached PDC cutter **300**, the second conducting material **520**, and the second insulating material **540** are positioned between the upper plate **552** and the base plate **554** such that the second insulating material **540** is positioned adjacently above and in contact with the base plate **554**. The upper plate **552** is moved towards the base plate **554** until the upper plate **552** applies a downward load **553** onto the cutting surface **312** of the leached PDC cutter **300**. When the downward load **553** is applied, the first conducting material **510** is deformed and adapted to the rough and very stiff cutting surface **312**, thereby minimizing contact resistance between the first conducting material **510** and the cutting surface **312** and greatly improving the capacitance measurement consistency. At this time, the base plate **554** also applies an upward load **555** onto the bottom surface **454** of the leached PDC cutter **300**. When the upward load **555** is applied, the second conducting material **520** is deformed and adapted to the rough and very stiff bottom surface **454**, thereby minimizing contact resistance between the second conducting material **520** and the bottom surface **454** and greatly improving the capacitance measurement consistency. In certain exemplary embodiments, the downward load **553** is equal to the upward load **555**. The downward load **553** and the upward load **555** is about one hundred pounds; however, these loads **553**, **555** range from about two pounds to about a critical load. The critical load is a load at which the leached PDC cutter **300** is damaged when applied thereto.

In one exemplary embodiment, the second insulating material **540** is positioned on the base plate **554**, the second conducting material **520** is positioned on the second insulating material **540**, the leached PDC cutter **300** is positioned on the second conducting material **520**, the first conducting material **510** is positioned on the leached PDC cutter **300**, and the first insulating material **530** is positioned on the first conducting material **510**. The upper plate **552** is moved towards the first insulating material **530** until the downward load **553** is

applied onto the leached PDC cutter 300. In an alternative exemplary embodiment, one or more components, such as the first insulating material 530 and the first conducting material 510, are coupled to the upper plate 552 prior to the upper plate 552 being moved towards the base plate 554. Although an Arbor Press 550 is used in the capacitance measuring system 500, other equipment capable of delivering equal and opposite loads to each of the cutting surface 312 and the bottom surface 454 of the leached PDC cutter 300 can be used in other exemplary embodiments.

One end of the first wire 430 is electrically coupled to the positive terminal 418 of the multi-meter 410, while the opposing end of the first wire 430 is electrically coupled to the first conducting material 510, which thereby becomes electrically coupled to the cutting surface 312 of the leached PDC cutter 300. In one exemplary embodiment, a clamp 590 is coupled to the opposing end of the first wire 430 which couples the first wire 430 to the first conducting material 510. One end of the second wire 440 is electrically coupled to the negative terminal 419 of the multi-meter 410, while the opposing end of the second wire 440 is electrically coupled to the second conducting material 520, which thereby becomes electrically coupled to the bottom surface 454 of the leached PDC cutter 300. In one exemplary embodiment, a clamp (not shown), similar to clamp 590, is coupled to the opposing end of the second wire 440, which couples the second wire 440 to the second conducting material 520. Hence, the circuit 505 is completed using the multi-meter 410, the first wire 430, the first conducting material 510, the leached PDC cutter 300, the second conducting material 520, and the second wire 440. The current is able to flow from the positive terminal 418 of the multi meter 410 to the cutting surface 312 of the leached PDC cutter 300 through the first wire 430 and the first conducting material 510. The current then flows through the leached PDC cutter 300 to the bottom surface 454 of the leached PDC cutter 300. When the multi-meter 410 is turned on, a voltage differential exists between the cutting surface 312 and the bottom surface 454. The current then flows from the bottom surface 454 to the negative terminal 419 of the multi-meter 410 through the second conducting material 520 and the second wire 440. The first insulating material 530 and the second insulating material 540 prevent the current from flowing into the Arbor Press 550. The capacitance measurement of the leached PDC cutter 300 is determined when the value displayed on the display 416 reaches a peak value or remains constant for a period of time.

FIG. 6 is a flowchart depicting a non-destructive leaching depth estimation method 600 in accordance with an exemplary embodiment of the present invention. Although FIG. 6 shows a series of steps depicted in a certain order, the order of one or more steps can be rearranged, combined into fewer steps, and/or separated into more steps than that shown in other exemplary embodiments. Referring to FIG. 6, the non-destructive leaching depth estimation method 600 begins at step 610. Upon starting at step 610, the non-destructive leaching depth estimation method 600 proceeds to step 620. At step 620, a calibration curve is obtained. The calibration curve can be generated from tests or acquired from elsewhere.

FIG. 7 is a graphical chart 700 depicting the calibration curve 705 that shows a relationship between capacitance 710 and actual leaching depth 720 for a plurality of leached components 300 (FIG. 3) in accordance with an exemplary embodiment of the present invention. Referring to FIG. 7, one or more of the leached components 300 (FIG. 3) have a different actual leaching depth 720 than at least one other leached component 300 (FIG. 3). The leached component 300 (FIG. 3) is the leached PDC cutter 300 (FIG. 3) according

to some exemplary embodiments; however, the leached component 300 can be only the PCD cutting table 310 (FIG. 3) or some other component that has a polycrystalline structure that has had at least some of the catalyst material removed from therein. Alternatively, in certain exemplary embodiments, the leached component 300 can be the chemically cleaned leached PDC cutter mentioned above.

The calibration curve 705 is generated by obtaining two or more leached components 300 (FIG. 3). The calibration curve 705 becomes more precise as more leached components 300 (FIG. 3) are used in generating the calibration curve 705. The capacitance data points 730 are obtained by measuring the capacitance 710 of each leached component 300 (FIG. 3). In certain exemplary embodiments, a plurality of capacitance data points 730 are obtained for each leached component 300 (FIG. 3). For example, the capacitance 710 is measured five times for each leached component 300 (FIG. 3). Obtaining a plurality of capacitance data points 730 for each leached component 300 (FIG. 3) improves the statistical significance of the capacitance data points 730 being collected. According to some exemplary embodiments, the leached component 300 (FIG. 3) is depolarized after each measurement for capacitance 710, before each measurement for capacitance 710, or before and after each measurement for capacitance 710. The leached component 300 is depolarized in one or a combination of different manners, such as grounding the leached component 300 (FIG. 3), wrapping the leached component 300 (FIG. 3) in aluminum foil or similar type material, heat treating the leached component 300 (FIG. 3), dropping the leached component 300 (FIG. 3) in a salt solution, or waiting to discharge the leached component 300 (FIG. 3). The leached component 300 (FIG. 3) is discharged by waiting about twenty-four hours, but the waiting time is greater or less in other exemplary embodiments. Depolarizing an object is known to people having ordinary skill in the art.

Once the capacitance 710 is measured for each leached component 300 (FIG. 3), the actual leaching depth 720 for each leached component 300 (FIG. 3) is determined. In some examples, the actual leaching depth 720 for a leached component 300 (FIG. 3) is determined by cutting the leached component 300 (FIG. 3), polishing the cut edge of the leached component 300 (FIG. 3), and visually measuring the actual leaching depth 720 under a magnifying device (not shown), such as a microscope. Although one method for determining the actual leaching depth 720 is described, other methods known to people having ordinary skill in the art can be used to determine the actual leaching depth 720 without departing from the scope and spirit of the exemplary embodiment. Each capacitance data point 730 is plotted on the graphical chart 700, where the actual leaching depth 720 is plotted versus the capacitance 710 that is measured. Once the capacitance data points 730 are plotted on the graphical chart 700, the calibration curve 705 is determined pursuant to methods known to people having ordinary skill in the art. For example, the calibration curve 705 is generated by using the average capacitance 711 of each leached component 300, the median capacitance 712 of each leached component, or by calculating the best fit curve. The best fit curve can be formed with a ninety-five percent confidence level, but this confidence level can range from about sixty percent to almost about one hundred percent, for example, 99.99 percent. The calibration curve 705 correlates the measured capacitance 710, which can be measured in nanofarads, with the actual leaching depth 720, which can be measured in microns. Although a few methods for generating the calibration curve 705 have been described, other methods, either destructive or non-destructive, can be used to generate the calibration curve 705.

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According to FIG. 7, the actual leaching depth 720 is directly related to the capacitance 710. Thus, as the actual leaching depth 720 increases, the capacitance 710 that is measured also increases. Conversely, as the actual leaching depth 720 decreases, the capacitance 710 that is measured also decreases. Additionally, the data scattering, or range of measured capacitance 710, is greater as the actual leaching depth 720 increases. Although FIG. 7 shows a direct relationship between the actual leaching depth 720 and the capacitance 710; in actuality, the relationship between the capacitance 710 and the actual leaching depth 720 is an inverse relationship. The formula to calculate the capacitance 710 is:

$$C = \epsilon_r A / (4\pi d)$$

where

C is the capacitance;

A is the area of overlap of the two plates;

$\epsilon_r$  is the relative static permittivity (sometimes called the dielectric constant); and

d is the separation between the plates.

Thus, as “d”, or the actual leaching depth 720, increases, the capacitance 710 decreases, and visa versa. The opposite phenomena is occurring in FIG. 7 because the by-product materials 398 (FIG. 3) present with the leached layer 354 (Figure) becomes polarized during the measurements, and thus the relative static permittivity is not constant.

Therefore, in certain exemplary embodiments, the leached layer 354 is treated, such as by chemical treatment, to have at least a portion of the by-product materials 398 (FIG. 3) removed. This treatment is dependent upon the methods and/or chemicals used to leach the PCD cutting table 310 (FIG. 3). This treated leached PDC cutter is used within the capacitance measuring system 400, 500 or within some other capacitance measuring system in lieu of the leached PDC cutter 300 (FIG. 3). The calibration curve that is determined using the treated leached PDC cutters would show the relationship between the actual leaching depth 720 and the capacitance 710 being an inverse relationship. In the methods using the treated leached PDC cutter, which has had at least a portion of the by-product materials 398 (FIG. 3) removed, the de-polarizing step is optional.

Referring back to FIG. 6, the non-destructive leaching depth estimation method 600 proceeds to step 630. At step 630, a similar type component, similar to leached cutter 300, is obtained. However, if the calibration curve was determined using treated leached PDC cutters, the similar type component is a different treated leached PDC cutter where the actual leaching depth is desired to be ascertained. This similar type component includes a polycrystalline structure that has a plurality of catalyst material therein. At least a portion of this catalyst material has been removed. This removed portion has an unknown depth, which is the leaching depth. The non-destructive leaching depth estimation method 600 proceeds to step 640. At step 640, the capacitance of the similar type component is measured. According to some exemplary embodiment, this capacitance is measured using the capacitance measuring system 400 (FIG. 4) or the capacitance measuring system 500 (FIG. 5). The non-destructive leaching depth estimation method 600 proceeds to step 650. At step 650, the estimated leaching depth of the similar type component is determined using the capacitance of the similar type component and the calibration curve 705 (FIG. 7). The estimated leaching depth is an estimation of the actual leaching depth and ranges from about one micron to about fifty microns from the actual leaching depth. The non-destructive

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leaching depth estimation method 600 proceeds to step 660, where the non-destructive leaching depth estimation method 600 ends.

FIG. 8 is a flowchart depicting a microstructural quality determination method 800 in accordance with an exemplary embodiment of the present invention. Although FIG. 8 shows a series of steps depicted in a certain order, the order of one or more steps can be rearranged, combined into fewer steps, and/or separated into more steps than that shown in other exemplary embodiments. Referring to FIG. 8, the microstructural quality determination method 800 begins at step 810. Upon starting at step 810, the microstructural quality determination method 800 proceeds to step 820. At step 820, one or more leached components that include a polycrystalline structure is obtained from a same leached batch. The same leached batch is a group of components that were leached in the same leaching process at the same time. The polycrystalline structure includes a leached layer and a non-leached layer being positioned adjacently below the leached layer. The non-leached layer includes a plurality of catalyst material therein, while the leached layer has had at least a portion of the catalyst material removed. The microstructural quality determination method 800 proceeds to step 830. At step 830, a plurality of capacitance values are measured for each of the leached components. The capacitance values are determined using the capacitance measuring system 400 (FIG. 4) or the capacitance measuring system 500 (FIG. 5). The microstructural quality determination method 800 proceeds to step 840. At step 840, an amount of data scattering is determined for each leached component. The amount of data scattering for a leached component is determined by a differential between the highest measured capacitance and the lowest measured capacitance for that leached component and by statistical results of where each measured capacitance lies. The microstructural quality determination method 800 proceeds to step 850. At step 850, a quality of the leached component is determined based upon the amount of data scattering. The quality of the leached component relates to the microstructural quality and/or the leaching quality. The microstructural quality relates to the porosity of the microstructure. The microstructural quality is a good quality when there is low porosity. Conversely, the microstructural quality is a poor quality when there is high porosity. The leaching quality is a good quality when there is less catalyst materials present within the leached layer of the polycrystalline structure. Conversely, the leaching quality is a poor quality when there is more catalyst materials present within the leached layer of the polycrystalline structure. In some exemplary embodiments, the quality of the leached component is considered to be good when the amount of data scattering is determined to be small. Conversely, the quality of the leached component is considered to be poor when the amount of data scattering is determined to be large. The relative terms of small and large are determined when comparing the data scattering of a first leached component to the data scattering of a second leached component that was leached in the same batch as the first leached component.

FIG. 9 is a data scattering chart 900 that shows the measured capacitance 710 for a plurality of leached cutters 922 from a same leaching batch in accordance with an exemplary embodiment of the present invention. Referring to FIG. 9, the data scattering chart 900 includes a cutter number axis 920 and a capacitance axis 910. The cutter number axis 920 includes the number of the cutters 922 tested. The capacitance axis 910 includes values for the measured capacitance 710. A capacitance data point 930 is obtained by measuring the capacitance of the cutter 922, or leached component 922, using the capacitance measuring system 400 (FIG. 4), the

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capacitance measuring system **500** (FIG. 5), or a similar type system. Each capacitance data point **930** is plotted on the data scattering chart **900**. Each leached component **922** has its capacitance measured a plurality of times. In some exemplary embodiments, five capacitance data points **930** are obtained for each leached component **922**, however, the number of measurements is greater or fewer in other exemplary embodiments. In some exemplary embodiments, a twenty-five percentile marking **950**, a fifty percentile marking **952** (or average), and a seventy-five percentile marking **954** is shown in the chart **900** for each leached component **922**. The area between the twenty-five percentile marking **950** and the seventy-five percentile marking **954** is shaded. The amount of data scattering is ascertained using this data scattering chart **900** and can be one or more of a differential between the highest and lowest capacitance measurements **710** for each leached component **922**, a range between the twenty-five percentile marking **950** and the seventy-five percentile marking **954**, or some similar observation made from the data scattering chart **900**.

According to FIG. 9, cutter number **4 923** and cutter number **9 924** have a larger data scattering than for example cutter number **6 925** or cutter number **7 926**. Hence, cutter number **4 923** and cutter number **9 924** have a poor leaching quality and/or a poor microstructural quality within the polycrystalline structure. The increase in amount of catalyst material within the polycrystalline structure causes this data scattering.

There are several benefits for non-destructively determining the leaching depth in an ultra-hard polycrystalline structure and/or characterizing at least a portion of the ultra-hard polycrystalline structure. For example, capacitance measurements can be made on all PDC cutters that are to be mounted and used in a tool, such as a drill bit, thereby being able to estimate the leaching depth in the ultra-hard polycrystalline structure included in the PDC cutter and/or characterizing at least a portion of the ultra-hard polycrystalline structure, such as the quality of the leaching and/or the quality of the microstructure. Hence, only certain PDC cutters are chosen to be mounted to the drill bit or other downhole tool. In another example, when a quantity of PDC cutters being leached within the same leaching batch are provided, such as one thousand PDC cutters, the capacitance of the PDC cutters are measured pursuant to the descriptions provided above. The PDC cutters that meet a desired quality and/or leaching depth are kept while the remaining PDC cutters that do not meet the desired leaching depth and/or quality are returned. Thus, in one exemplary embodiment, although one thousand PDC cutters being leached from the same batch are provided, two hundred PDC cutters, or twenty percent, may be retained while the remaining are returned. Thus, only the higher quality and/or the proper leaching depth PDC cutters are paid for and retained, which results in the PDC cutters performing better during their application.

Although each exemplary embodiment has been described in detail, it is to be construed that any features and modifications that are applicable to one embodiment are also applicable to the other embodiments. Furthermore, although the invention has been described with reference to specific embodiments, these descriptions are not meant to be construed in a limiting sense. Various modifications of the disclosed embodiments, as well as alternative embodiments of the invention will become apparent to persons of ordinary skill in the art upon reference to the description of the exemplary embodiments. It should be appreciated by those of ordinary skill in the art that the conception and the specific embodiments disclosed may be readily utilized as a basis for

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modifying or designing other structures or methods for carrying out the same purposes of the invention. It should also be realized by those of ordinary skill in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims. It is therefore, contemplated that the claims will cover any such modifications or embodiments that fall within the scope of the invention.

What is claimed is:

1. A capacitance measuring system, comprising:

a capacitance measuring device comprising a positive terminal and a negative terminal;

a leached polycrystalline diamond compact cutter comprising a polycrystalline structure and a substructure, the polycrystalline structure comprising a leached layer and an unleached layer positioned adjacent to the leached layer, the leached layer having at least a portion of a catalyst material removed from therein;

a first conducting component for contacting a first surface of the leached polycrystalline diamond compact cutter; a first wire for electrically coupling the positive terminal to the first conducting component;

a second conducting component for contacting a second surface of the leached polycrystalline diamond compact cutter, the second surface being positioned opposite of the first surface;

a second wire for electrically coupling the negative terminal to the second conducting component; and

a press for firmly engaging the conducting components with the respective surfaces to form a circuit, wherein the capacitance measuring device is operable to measure a capacitance of the leached polycrystalline diamond compact cutter via the circuit.

2. The capacitance measuring system of claim 1, wherein the capacitance measuring device comprises a multi-meter.

3. The capacitance measuring system of claim 1, wherein the first conducting component and the second conducting component are substantially similar in size and shape.

4. The capacitance measuring system of claim 1, wherein each conducting component is deformable for adapting to the respective surface.

5. The capacitance measuring system of claim 1, further comprising:

a first insulating component for positioning between the first conducting component and an upper plate of the press; and

a second insulating component for positioning between the second conducting component and a base plate of the press.

6. The capacitance measuring system of claim 1, wherein the leached layer has at least a portion of a by-product material removed from therein.

7. A method of characterizing a quality of a polycrystalline structure, comprising:

obtaining a batch of leached components, each leached component comprising a polycrystalline structure, each polycrystalline structure comprising a leached layer and an unleached layer positioned adjacent to the leached layer, each leached layer having at least a portion of a catalyst material removed from therein;

destructively testing a plurality of the leached components from the batch to obtain calibration data of actual leaching depths;



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measuring a capacitance value of an intact leached component from the batch; and  
determining an estimated leaching depth of the intact leached component using the measured capacitance value and the calibration data.

8. The method of claim 7, further comprising obtaining a calibration curve from the calibration data, wherein the calibration curve is used to determine the estimated leaching depth.

9. The method of claim 7, wherein:

multiple capacitance values are measured for the intact leached component,

the method further comprises determining an average of the multiple measured values, and

the average is used to determine the estimated leaching depth.

10. The method of claim 7, further comprising depolarizing the intact leached component.

11. The method of claim 10, wherein depolarizing the intact leached component is performed in at least one of before measuring the capacitance value and after measuring the capacitance value.

12. The method of claim 10, wherein depolarizing the intact leached component comprises at least one of grounding the leached component, wrapping the leached component in a depolarizing material, heat treating the leached component, placing the leached component in a salt solution, and waiting a period of time.

13. The method of claim 7, further comprising cleaning the polycrystalline structure of the intact leached component from one or more by-product materials, wherein the by-product materials were deposited within the polycrystalline structure during a leaching process that removes at least a portion of the catalyst material from therein and forms the leached component.

14. The method of claim 7, wherein:

a plurality of capacitance values are measured for the intact leached component, and

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the method further comprises:

measuring a plurality of capacitance values of a second intact leached component from the batch; and

using the pluralities of measured capacitance values to determine a second quality of microstructures of the polycrystalline structures of the intact leached components.

15. The method of claim 14, further comprising:

determining a data scattering range for each of the intact leached components from the plurality of measured capacitance values,

wherein:

the second quality is determined using the data scattering ranges, and

the microstructure being less porous when the data scattering range is less in comparison to the data scattering range of the other intact leached component.

16. The method of claim 7, wherein the leached layer of the intact leached component has at least a portion of a by-product material removed from therein.

17. The method of claim 7, further comprising:

measuring capacitance values of the rest of the intact leached components in the batch;

determining estimated leaching depths of the rest of the intact leached components using the respective measured capacitance values and the calibration data;

selecting acceptable intact leached components using the estimated leaching depths; and

mounting at least a portion of the acceptable intact leached components to a tool.

18. The method of claim 7, wherein the destructive testing comprises:

cutting each leached component;

polishing a cut edge of each cut component; and

visually measuring the actual leaching depth of each polished edge using a magnifying device.

\* \* \* \* \*